(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number : **0 590 922 A2**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number : **93307658.0**

(51) Int. Cl.^{5} : **H04N 1/41**

(22) Date of filing : **28.09.93**

(30) Priority : **02.10.92 US 956128**

(43) Date of publication of application :
06.04.94 Bulletin 94/14

(84) Designated Contracting States :
DE FR GB

(71) Applicant : **XEROX CORPORATION**
Xerox Square
Rochester New York 14644 (US)

(72) Inventor : **Eschbach, Reiner**
812 Westwood Trail
Webster, New York 14580 (US)

(74) Representative : **Hill, Cecilia Ann et al**
Rank Xerox Patent Department, Albion House,
55-59 New Oxford Street
London WC1A 1BS (GB)

(54) **Improved decompression of standard ADCT-compressed images.**

(57) A method of decompressing a document image compressed with JPEG ADCT or the like method of compression includes : a) receiving (300) encoded quantized transform coefficient blocks for the original image ; b) removing (302) any lossless encoding of the quantized transform coefficient blocks for the original image ; c) multiplying (304) each quantized transform coefficient in a block by a corresponding quantizing value from the quantization table to obtain a block of received transform coefficients ; d) recovering the image by applying an inverse transform operation (306) to the received transform coefficients ; e) reducing (308) high frequency noise appearing in the recovered image as a result of the lossy quantization process, while preserving edges, whereby the appearance of the recovered image is rendered more visually appealing ; f) changing (310) the filtered recovered image into blocks of new transform coefficients by the forward transform coding operation using the frequency space transform compression operation ; g) comparing (312) each block of new transform coefficients to a corresponding block of received transform coefficients and the selected quantization table, to determine (314) whether the filtered recovered image is derivable from the original image ; and h) upon the determination transferring (316,320) the filtered recovered image to an output buffer.

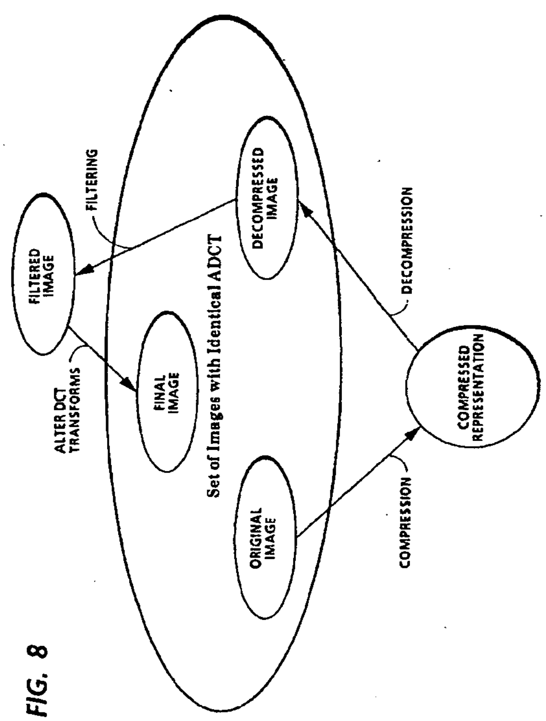
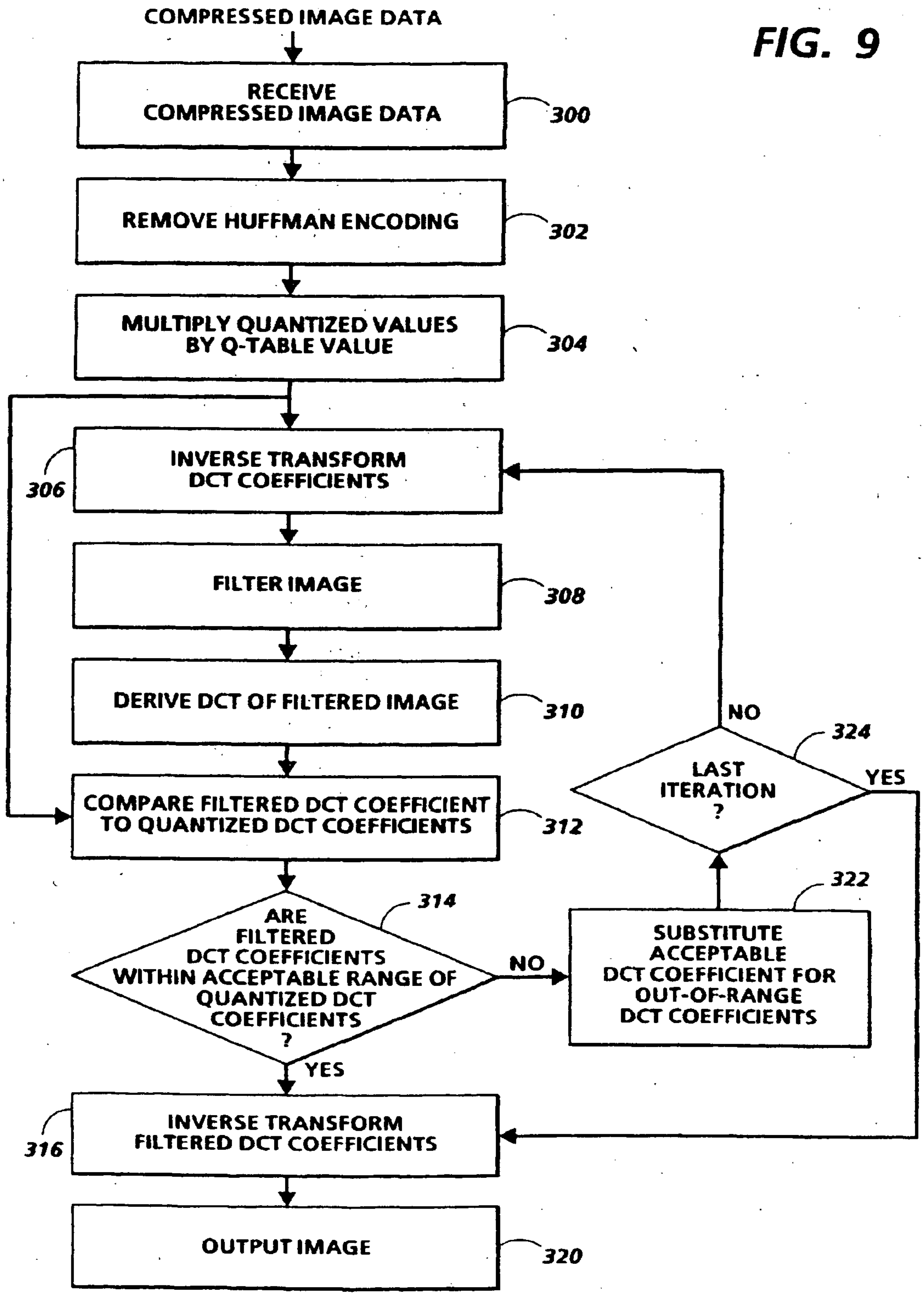


FIG. 8

EP 0 590 922 A2

FIG. 9


COMPRESSED IMAGE DATA
RECEIVE COMPRESSED IMAGE DATA
300
REMOVE HUFFMAN ENCODING
302
MULTIPLY QUANTIZED VALUES BY Q-TABLE VALUE
304
INVERSE TRANSFORM DCT COEFFICIENTS
306
FILTER IMAGE
308
DERIVE DCT OF FILTERED IMAGE
310
COMPARE FILTERED DCT COEFFICIENT TO QUANTIZED DCT COEFFICIENTS
312
ARE FILTERED DCT COEFFICIENTS WITHIN ACCEPTABLE RANGE OF QUANTIZED DCT COEFFICIENTS ?
314
NO
YES
SUBSTITUTE ACCEPTABLE DCT COEFFICIENT FOR OUT-OF-RANGE DCT COEFFICIENTS
322
LAST ITERATION ?
324
NO
YES
INVERSE TRANSFORM FILTERED DCT COEFFICIENTS
316
OUTPUT IMAGE
320

The present invention is directed generally to the production of document images and, in particular, to a method of improving the appearance of a decompressed document image while maintaining fidelity with an original document image from which it is derived.

Data compression is required in data handling processes, where too much data is present for practical applications using the data. Commonly, compression is used in communication links, where the time to transmit is long, or where bandwidth is limited. Another use for compression is in data storage, where the amount of media space on which the data is stored can be substantially reduced with compression. Yet another application for compression is in a digital copier where an intermediate storage of data is required for collation, reprint or any other digital copier function. Generally speaking, scanned images, i.e., electronic representations of hard copy documents, are commonly large, and thus are desirable candidates for compression.

Many different compression techniques exist, and many are proprietary to individual users. However, standards are desirable whenever intercommunication between devices will be practiced. Particularly with the advent of multimedia communication, where formerly dissimilar devices are required to communicate, a common standard will be required. An example is the current desirability of FAX machines to be able to communicate with printers. Currently, compression standards are generally distinct for different devices.

Three major schemes for image compression are currently being studied by international standardization groups. A first, for facsimile type image transmission, which is primarily binary, is under study by the JBIG (Joint Binary Image Group) committee, a second for TV and film, a standard is worked on by the MPEG (Motion Pictures Expert Group). For non-moving general images, i.e., still images which are more general than the ones covered by JBIG, the group JPEG (Joint Photographic Expert Group) is seeking to develop a device independent compression standard, using an adaptive discrete cosine transform scheme.

ADCT (Adaptive Discrete Cosine Transform, described for example, by W. H. Chen and C. H. Smith, in "Adaptive Coding of Monochrome and Color Images", IEEE Trans. Comm., Vol. COM-25, pp. 1285-1292, November 1977), as the method disseminated by the JPEG committee will be called in this application, is a lossy system which reduces data redundancies based on pixel to pixel correlations. Generally, in images, on a pixel to pixel basis, an image does not change very much. An image therefore has what is known as "natural spatial correlation". In natural scenes, correlation is generalized, but not exact. Noise makes each pixel somewhat different from its neighbors.

Generally, as shown in Figure 1, the process of compression requires a tile memory 10 storing an M x M tile of the image. We will use square tiles in the description based on the JPEG recommendations, but it has to be noted that methods in accordance with the invention, described below, can be performed with any form of tiling. From the portion of the image stored in tile memory, the discrete cosine transform (DCT), a frequency space representation of the image is formed at transformer 12. Hardware implementations are available, such as the C-Cube Microsystems CL550A JPEG image compression processor, which operates in either the compression or the decompression mode according to the proposed JPEG standard. A divisor/quantization device 14 is used, from a set of values referred to as a Q-Table, stored in a Q table memory 16, so that a distinct Q table value is divided into the DCT value, returning the integer portion of the value as the quantized DCT value. A Huffman encoder 20, using statistical encoding of the quantized DCT values, generates the compressed image that is output for storage, transmission, etc.

The current ADCT compression method divides an image into M x M pixel blocks, where M = 8. The selection of M = 8 is a compromise, where the larger the block given, the higher the compression ratio obtainable. However, such a larger block is also more likely to have non-correlated pixels within the block, thereby reducing the compression ratio. If the block was smaller, greater correlation within the block might be achieved, but less overall compression would be achieved. Particularly within a document image, edges of the image are more likely to be encountered within an 8 x 8 block, than would be the case for a scene forming a natural image. Thus, the assumption of spatial correlation fails to some extent. A major problem addressed by the present invention, as will become more apparent hereinbelow, is that the assumptions of the ADCT proposal work well for photographs containing continuous tones and many levels of gray pixels, but often work poorly for the reproduction of document images, which have significant high frequency components and many high contrast edges.

Compression schemes tend to use a set of basis functions to utilize the intra block correlations. Basis functions define the data as a projection onto a set of orthogonal functions on an interval. ADCT uses cosine functions as the basis functions and the Discrete Cosine Transform (DCT) as the projection step. In the first step of the ADCT standard, the image is tiled into 8 x 8 blocks. Within each block, a set of 64 DCT coefficients is determined for the pixels in the block. The DCT coefficients represent the coefficients of each cosine term of the discrete cosine transform of the 8 x 8 block.

Referring now to Figure 2A, an array of 64 gray

level values representing 64 pixels in an 8 x 8 block of the image is shown. This 8 x 8 block is transformed according to the JPEG ADCT specifications giving the DCT coefficients shown in Figure 2B. These coefficients still completely describe the image data of Figure 2A, but in general larger values will now cluster at the top left corner in the low spatial frequency region. Simultaneously, in the vast majority of images as the frequency of the image increases, the coefficient values in the lower right hand portion of the grid tend towards zero.

Generally, the human eye tends to see low frequencies in an image best. At higher frequencies, changes from amplitude to amplitude are unnoticeable, unless such changes occur at extremely high contrast. This is a well known effect of the Human Visual System and extensively documented, see e.g. "Visual Performance and Image Coding" by P. Roetling, Proceedings of the S.I.D. 17/2 pp. 111 - 114 (1976). The ADCT method makes use of the fact that small amplitude changes at high frequencies can be generally ignored.

The next step in the ADCT method involves the use of a quantization or Q-matrix. The Q-matrix shown in Figure 2C is a standard JPEG-suggested matrix for compression, but the ADCT method and methods in accordance with the present invention, described below, can also operate using other Q-matrices (or Q-Tables). The matrix incorporates the effect that lower frequencies are roughly more important than high frequencies by introducing generally larger quantization steps, i.e. larger entries, for larger frequencies. However, the table also attempts to internally construct some desirable variations from the general assumption. Accordingly, the values in the table do vary with frequency, where the exact variation might be a function of the human visual system, of the document type expected, i.e.: photo, text, graphic, etc., or of some other application dependent parameter. Each of the DCT values from Figure 2B is divided by a corresponding Q-matrix value from Figure 2C giving quantized DCT (QDCT) values by way of:

$$QDCT[m][n] = INT\{DCT[m][n] \div Q - Table[m][n] + ½\}$$

where INT{A} denotes the integer part of A

The remainder from the division process is discarded, resulting in a loss of data. Here and in the following we use the term division to describe the process detailed in ADCT including the methods for handling truncation and round-off. Furthermore, since the Q values in the lower right hand portion of the table tend to be high, most of the values in that area go to zero, unless there were extremely high amplitudes of the image at the higher frequencies.

After deriving the quantized set of DCT values, shown in Figure 2D, pixels are arranged in the order of a space filling zigzag curve and a statistical encoding method, such as the Huffman process, is used to generate the transmitted signal. This statistical coding is performed in a lossless way and the only loss introduced in the compression is the one generated by the quantization of the DCT coefficients using the Q-Table.

ADCT transforms are well known, and hardware exists to perform the transform on image data, e.g., US-A 5,049,991 to Nihara, US-A 5,001,559 to Gonzales et al., and US-A 4,999, 705 to Puri. The primary thrust of these particular patents, however, is moving picture images, and not document images.

To decompress the now-compressed image, and with reference to Figure 1, a series of functions or steps are followed to reverse of the process described. The Huffman encoding is removed at decoder 50. The image signal now represents the quantized DCT coefficients, which are multiplied at signal multiplier 52 by the Q table values in memory 54 in a process inverse to the compression process. At inverse transformer 56, the inverse transform of the discrete cosine transform is derived, and the output image in the spatial domain is stored at image buffer 58.

In the described decompression method, Huffman encoding is removed to obtain the quantized DCT coefficient set. Each member of the set is multiplied by a Q-Table value resulting in the DCT coefficients shown in Figure 3A by using the data of Figure 2C and 2D by ways of:

$$DCT[m][n] = QDCT[m][n] \times Q - Table[m][n].$$

However, the result shown in Figure 3A is not the original set of DCT coefficients shown in Figure 2B, because the remainders calculated for the original quantization of the DCT coefficients with the Q-Table in the compression process have been lost. In a standard ADCT decompression process, the inverse discrete cosine transform of the set of DCT coefficients is derived to obtain image values shown in Figure 3B.

The described process does not work to reproduce the best images. Clearly, it cannot reproduce the original image, since data within the image was discarded in the compression-quantization step. Failures are noted wherever strong edges, commonly present in text, appear. Particularly, at such edges "ringing artifacts" or in some references, "mosquito noise" is noted. These problems occur in text, graphics and halftones, components very common in document images. In addition to mosquito noise or ringing artifacts, a blocking artifact often appears associated with image areas with slowing varying grays, where each M x M block which formed the calculation of the compression basis appears visible. In either case, a problem has occurred.

In order to remove the artifacts noted, two methods of attacking the problem have been attempted. In a first method, the decompressed image is post processed, i.e., after the image has been fully decompressed, an attempt is made to improve the image. Of course, such processing can never go back to the

original image, because that image has been lost. Such processes are demonstrated in the article "Reduction of Blocking Effects in Image Coding" by Reeve, III et al., Optical Engineering, January/February, 1984, Vol. 23, No. 1, p. 34, and "Linear Filtering for Reducing Blocking Effects in Orthogonal Transform Image Coding", by C. Avril et al., Journal of Electronic Imaging, April 1992, Vol. 1(2), pp. 183-191. However, this post-processing of the image leads to a reconstruction that could not have been the real source image and subsequent compression/decompression steps as they are possible in electronic imaging applications will lead to potentially larger and larger deviations between reconstruction and original.

Another approach to the problem is through an iterative decoding process using the known bandlimit of the data. In this method, using the compressed form of the image again, different blocks, perhaps 32 x 32, are used to decode the image. In one example, "Iterative Procedures for Reduction of Blocking Effects in Transform Image Coding", by R. Rosenholtz et al., SPIE, Vol. 1452, Image Processing Algorithms and Techniques II, (1991), pp. 116-126, a method of blurring the overall image was considered, with the hope that such blurring would tend to smooth out the block artifacts noted above.

In accordance with the invention, there is provided a method of decompressing a compressed document image, wherein the decompressed image is filtered, and the filtered image is compared to the set of images derivable from the original image, before compression, to reduce image noise and assure that the decompressed image is within a known range of images.

More particularly, the present invention provides a method of improving the appearance of a decompressed document image while maintaining fidelity with an original document image from which it is derived, wherein for compression, an original document image is divided into blocks of pixels, said blocks of pixels are changed into blocks of transform coefficients by a forward transform coding operation using a frequency space transform operation, said transform coefficients subsequently quantized with a lossy quantization process in which each transform coefficient is quantized according to a quantizing value from a quantization table and the result is used as a quantized transform coefficient, the method including the decompression steps of:

a) receiving said quantized transform coefficient blocks for said original image;

b) dequantizing the transform coefficients in a block according to a corresponding quantizing value from the quantization table to obtain a block of received transform coefficients;

c) recovering the image by applying an inverse transform operation to the received transform coefficients;

d) with a selected non-linear filter, reducing high frequency noise appearing in the recovered image as a result of the lossy quantization process, while preserving edges, whereby the appearance of the recovered image is rendered more visually appealing;

e) changing the filtered recovered image into blocks of new transform coefficients by the forward transform coding operation using the frequency space transform compression operation;

f) comparing each block of new transform coefficients to a corresponding block of received transform coefficients and the selected quantization table, to determine whether the filtered recovered image is derivable from the original image; and

g) upon said determination transferring the filtered recovered image to an output buffer.

In accordance with one aspect of the invention, there is provided a method of improving the appearance of a decompressed document image while maintaining fidelity with an original document image from which it is derived, wherein for compression, an original document image is divided into blocks of pixels, the blocks of pixels are changed into blocks of transform coefficients by a forward transform coding operation using a frequency space transform compression operation, the transform coefficients subsequently quantized with a lossy quantization process in which each transform coefficient is divided by a quantizing value from a quantization table and the integer portion of a result is used as a quantized transform coefficient, and the blocks of quantized transform coefficients are encoded with a lossless encoding method, the method including the decompression steps of: a) receiving the encoded quantized transform coefficient blocks for the original image; b) removing any lossless encoding of the quantized transform coefficient blocks for the original image; c) multiplying each quantized transform coefficient in a block by a corresponding quantizing value from the quantization table to obtain a block of received transform coefficients; d) recovering the image by applying an inverse transform operation to the received transform coefficients; e) with a selected filter, reducing high frequency noise appearing in the recovered image as a result of the lossy quantization process, while preserving edges, whereby the appearance of the recovered image is rendered more visually appealing; f) changing the filtered recovered image into blocks of new transform coefficients by the forward transform coding operation using the frequency space transform operation; g) comparing each block of new transform coefficients to a corresponding block of received transform coefficients and the selected quantization table, to determine whether the filtered recovered image is derivable from the original image; and h) upon the determination transferring

the filtered recovered image to an output buffer.

In accordance with another aspect of the invention, in such a decompression process, step g) may include the additional steps of: 1) determining that the block of new transform coefficients is not derivable from the original image; and 2) altering individual new transform coefficients, so that a block of altered new transform coefficients is derivable from the original image, 3) recovering the image from the blocks of altered new transform coefficients.

In accordance with still another aspect of the invention, the steps e-g may be repeated iteratively until a selected condition occurs. Possible selected conditions are i) a number of iterations, ii) no corrections are required to the transformed image, or iii) no changes have been made in successive iterations to the inverse transformed image.

By altering the decompression process, as opposed to altering the compression process, integrity and compatibility with the JPEG standard process are maintained independent on the number of compression/decompression cycles the document image data undergo. Additionally, the process can be selectively used, based on the image input, and on whether improvements can be made using the decompression process.

By way of example only, embodiments of the invention will be described with reference to the accompanying drawings, in which:

Figure 1 (already described) shows a functional block diagram for the prior art ADCT compression/recompression process;

Figure 2A (already described) shows an 8 x 8 block of image data to be compressed; Figure 2B (already described) shows the discrete cosine values as determined, giving a frequency space representation of the image of Figure 2A; Figure 2C (already described) shows the default Q-Table used in the examples; and Figure 2D (already described) shows the quantized discrete cosine values as determined;

Figure 3A (already described) shows the DCT values regenerated from the data of Figure 2A by use of the Q-Table of Figure 2C, and Figure 3B (already described) shows the corresponding 8 x 8 reconstructed image data block.

Figure 4 shows the principle of a single set of quantized ADCT values representing a class of distinct and possible images;

Figures 5A-C show numerical examples for the case of a multiple source image being represented by a single set of quantized ADCT value;

Figure 6 shows the effect of the edge-preserving lowpass filter used in the examples;

Figure 7A shows one exemplar image block along with its neighborhood and the filter context; Figure 7B shows the results of the filtering process on the image; Figure 7C shows the DCT transform of the image, the circles illustrating that the image is not within the set of possible images; Figure 7D shows an alteration to the DCT transform of the image; and Figure 7E shows the inverse transform of the altered DCT transform;

Figure 8 shows a graphical representation of Figure 7, where the filtered image lies outside the set of images with identical ADCT representations; and

Figure 9 shows a flow chart of an iterative decompression process.

Referring now to the drawings, we note initially, that while it is impossible to return to the exact image which was compressed originally in the compression process, because data has been lost in the compression process, it is possible to return to an image which is similar in some respect to the original compressed image, as will be further described hereinafter. Secondly, it is possible to correct the basic image defects that are appearing in the image. With reference now to Figure 4, a general overview of the compression/decompression process is shown. There exists a set of images which are distinct from each other, but which are similar in the respect that each image in the set compresses to the same ADCT representation. Therefore, any decompression process should produce an output image which is within this set. The knowledge of the set of possible images is coded by the Q-Table used. Since the Q-Table represents divisors of the discrete quantized transform coefficients, and as a result of the quantization process fractional portions of each coefficient are discarded, then the set of possible images represents all those images from which the same quantized transform coefficients can be determined about a range of possible coefficient values for each term of the transform.

With reference now to Figure 5A, there is shown a set of possible source images 100, 102, 104 and 106, each consisting of image signals having a gray density value, ranging between 0 and 256 for the example, followed by their corresponding DCT coefficients as a result of the DCT conversion (for this illustration, illustrated as the DCT 108. These images represent portions of document images, generated by scanning an original document with an input scanner or created an electronic document on a computer, etc. As can be seen, the images are distinct and the DCT coefficients 110, 112, 114 and 116 shown in Figure 5B are distinct. The DCT coefficients are quantized at quantization 118 using the corresponding entries in the Q-Table 119 shown in Figure 5C. In this example the top left entry of the DCT coefficients is divided by the top left entry [16] in the Q-Table. Using a rounding operation for the fractional part, the result for those coefficients are

in set 110, 157/16 = 9.81 rounds to 10,
in set 112, 160/16 = 10
in set 114,163/16 = 10.19 rounds to 10, and

in set 116, 162/16 = 10.13 rounds to 10.

All of the top left entries in the table of DCT coefficients are therefore mappable to the same quantized DCT coefficients (set 120 shown in Figure 5C) using this Q-Table. The same is true for all other DCT coefficients shown in Figure 5A. The compressed data of set 120, therefore describes a set of possible source images rather than a unique source image with a subset of those possible source images shown in Figure 5A. The determination that an 8 x 8 image block is a possible source of the quantized DCT coefficients can be derived by considering the fact that the Q-Table entries define the quantizers and therefore the accuracy of the DCT coefficients. In the example given in Figure 5B, the top left entry is bounded by 153 $\leqq$ entry $\leqq$ 168, spanning 16 values, any value in that range can be used as DCT coefficient without altering the compressed data. It is this "non-uniqueness" that is utilized in the method as described below, by selecting a possible source image that is i) a possible source image conforming with the compressed data and ii) an image that conforms to the model of a document image. In this way the method differs from previous methods in which the ultimate image derived, does not conform to the compressed data as in post filtering methods, or does not use a source image model to restrict the decompression, but rather used a sampling consideration to blur the image.

In order to define an expectation for the input document image, it is noted that the image problem that results from the decompression process is ringing, or high frequency noise. Elimination of the high frequency noise is desirable, requiring a low pass filter. Unfortunately, the ringing occurs at edges, which are very common and important in document images. Accordingly, since edges represent high frequencies, which should not be removed, a simple low pass filter is not adequate, because it would destroy the edge information, i.e.: the readability of characters or the definition of lines, along with the reduction of noise. Rather, a low pass filter that preserves edges is required. Such a filter is a non-linear filter which might be an order statistical filter (or median filter), a sigma filter or the like.

In our present example and with reference to Figure 6, the sigma filter operates on the image using a noise value or delta of $\Delta = 32$ in this example. The pixel with value 231 is surrounded by pixels that do not deviate from this value by more than Δ, and therefore, an output value 218 is derived by averaging over all 9 pixels in a 3 x 3 area. The pixel with value 40 is surrounded by pixels within the range as well as by pixels exceeding the range, resulting in an output value 55 generated by averaging over 3 pixels.

With reference now to Figure 7A, a set of decompressed pixels and their gray values, in an 8 x 8 pixel block within a 10 x 10 pixel neighborhood is indicated by the black lines segregating the neighborhood from the remainder of the image, is shown. At borders of the image, we simply replicate pixels, and in Figure 7A this is represented in the leftmost column and the bottom row. The sigma filter is represented as an averaging function performed over pixels in a 3 x 3 neighborhood that do not deviate from the center pixel by more than a value of 32. In Figure 7A, values 155, 96, and 141 (all circled), deviate from the center pixel 206 (identified by a square) by more than a value of 32 (the noise value or Δ). Applying this filter, a modified image is obtained from the gray level pixels, given in Figure 7B and resulting in a new value of 208 (identified by a square) for the pixel.

Having obtained a filtered image, which has attenuated the high frequency noise within the decompressed image, a comparison to the original image is obtained to assure fidelity with the original image. The DCT of the image is derived, shown in Figure 7C. The results are directly compared with the original compressed image (compared, for example to DCT coefficient sets 110, 112, 114, and 116, and Q-Table 119, of Figures 5B and 5C). Each position in the DCT set has a range of acceptable values, and in the example of Figure 7C, the value at position 3,1 (value of 74 circled) is beyond the range of acceptable values earlier determined to be 75 to 84 by means of 8 = INT{acceptable value ÷ 10 + ½}, where '8' is the quantized DCT coefficient and '10' is the corresponding Q-Table entry. Accordingly, value 75 is substituted for value 74. In other words, the transform values have been altered so that the image which was outside the set of possible images, is now just within that set (see Figures 5A and 5B). While a value just inside the acceptable range is selected in this example, experience may show that values at other positions in the range might also be suitable substitutes for out-of-range values. Figure 7D shows the corrected DCT coefficient at position 3,1 with an additional modified entry at position 1, 4 (circled). From Figures 7C and 7D it is clear, that a simple filtering of a decompressed image does not guarantee that the result of the filtering operation is an image that was a possible source image for the compressed data, thus generating an image that is in violation of the DCT data. The inverse transform of the altered DCT set is derived, and a set of gray image pixels is again obtained as shown in Figure 7E. All pixels in Figure 7E that have been altered in reference to Figure 7B are again circled. It should be noted that the values given in Figure 7E are the values of a possible original image, whereas two values given in Figure 7B were in violation of acceptable DCT ranges.

The process of filtering the image, transforming to frequency space, comparing and altering the frequency space values, and retransforming back to gray image pixels may be reiterated a number of times. The number of iterations can be selected on a basis of no changes in the DCT transform (i.e., there

is convergence). Alternatively, the process may be iterated until there are no further changes in the image (another type of convergence). In yet another alternative, the number of iterations set to a fixed number, or a fixed number can serve as an upper limit of iterations.

In the iterative process used, the noise estimate used in the filter may be changed for each iteration. That is, instead of assuming $\Delta = 32$ and using that value for each iteration, values of two thirds of Δ in the second iteration, and one third Δ in third iteration for a three iteration case, might be used. We also might filter and sharpen (applying a different filter) in sequential operations.

Now the image is a new one. First, it is noted that this image is a possible original image, which could have resulted in the compressed original image. Therefore, there is some fidelity to the original image. The image has been smoothed at least once to remove high frequency noise while enhancing or maintaining edges. The correction may have introduced changes in the image, but a compressed version of the filtered image has been compared to the original compressed image (the original possible set) to assure fidelity. The filtered image was corrected as required. It is assumed that the corrected filtered image is better than the filtered image because it is in complete agreement with the range of possible images.

Figure 8 illustrates the principal of the method. The original image is compressed; the compressed representation is decompressed. The decompressed image is filtered to improve appearance, but in doing so, it is forced outside the range of images that are acceptable. The DCT representation of the image is therefore altered, in order to force the image into the acceptable range of images.

With reference now to Figure 9, a flow chart of the iterative ADCT decompression/reconstruction is provided showing the additional operations of the method in accordance with the present invention. An image compressed in accordance with the ADCT compression method with statistical encoding is obtained at step 300. The statistical encoding is removed at step 302 to obtain quantized DCT coefficients. At step 304, the quantized DCT coefficients are multiplied by values in the Q table to obtain the set of DCT coefficients. At step 306, the inverse transform of the DCT coefficients is derived to produce the gray level image. Deviating from the normal process, at step 308 the 8 x 8 output block is filtered. At step 310, the filtered image output is used to generate a set of DCT coefficients. At step 312, the filtered image DCT coefficients are compared to the DCT coefficients obtained at step 312, and an acceptable range about each value. At step 314, if the filtered image DCT coefficients are within the acceptable range about each value, then at step 316, the inverse transform of the DCT coefficients is derived to produce the gray level image. At step 320, the gray image is directed to an output. If the filtered image DCT coefficients are not within the acceptable range about each value, then at step 322, acceptable values are substituted for out-of-range values, and the process is repeated from step 306. Not shown, a counter may be incremented to limit the number of iterations. If, at step 324 the limit of the iteration number is reached, the data is transferred to block 316 for subsequent output through block 320. This step guarantees that the output gray level image is a valid image for the compressed description received at block 300.

It should be noted that one specific filter type and one specific conflict resolution for the DCT coefficients was used in the examples. Clearly, different filters are possible, including general order statistic filters and "find-and-replace" filters. Also, the filter can be based on the local characteristics of the 8 x 8 block. An example is an edge preserving smoothing filter that uses a fraction of the dynamic range of the local 8 x 8 blocks, and/or the Q-matrix to determine the maximum noise variation encountered in the block. Another option for the manipulation in the image domain, in contrast to the DCT domain, is the thresholding of data if a binary original is assumed. This assumption, however, has to be tested in a DCT domain and the thresholding should only be accepted if the DCT coefficients after thresholding are in agreement with the DCT coefficients before thresholding.

Different options exist for the conflict resolution of the DCT coefficients. Convergence speed can be improved by modifying the algorithm slightly. Possible modifications include, e.g., the addition of noise into the modified DCT coefficients. Finally, the number of iterations can be a function of the local 8 x 8 block characteristics rather than using a fixed number as used in the examples.

Claims

1. A method of improving the appearance of a decompressed document image while maintaining fidelity with an original document image from which it is derived, wherein for compression, an original document image is divided into blocks (Fig. 2A) of pixels, said blocks of pixels are changed into blocks (Fig. 2B) of transform coefficients by a forward transform coding operation using a frequency space transform operation, said transform coefficients are subsequently quantized with a lossy quantization process in which each transform coefficient is quantized according to a quantizing value from a quantization table (Fig. 2C) and the result (Fig. 2D) is used as a quantized transform coefficient, the method including the decompression steps of:

a) receiving (300) said quantized transform coefficient blocks for said original image;

b) dequantizing (304) the transform coefficients in a block according to the quantization table (119) to obtain a block of received transform coefficients;

c) recovering the image by applying an inverse transform operation (306) to the received transform coefficients;

d) with a selected filter, reducing (308) high frequency noise appearing in the recovered image as a result of the lossy quantization process, while preserving edges, whereby the appearance of the recovered image is rendered more visually appealing;

e) changing the filtered recovered image into blocks of new transform coefficients by the forward transform coding operation (310) using the frequency space transform compression operation;

f) comparing (312) each block of new transform coefficients (Fig. 7C) to a corresponding block of received transform coefficients and the selected quantization table (Figs. 5B and 5C), to determine (314) whether the filtered recovered image is derivable from the original image; and

g) upon said determination transferring (316,320) the filtered recovered image to an output buffer.

2. A method as claimed in claim 1, wherein step f) includes the additional steps of

1) determining that the block of new transform coefficients is not derivable from the original image; and

2) altering (322) individual new transform coefficients, so that a block of altered new transform coefficients (Fig. 7D) is derivable from the original image;

3) recovering the image (Fig. 7E) from the blocks of altered new transform coefficients.

3. A method as claimed in claim 2, including repeating steps d-f iteratively until a selected condition occurs.

4. A method as claimed in any one of the preceding claims, wherein the forward transform coding operation using the frequency space transform operation is a discrete cosine transform.

5. A method as claimed in any one of the preceding claims, wherein, for compression, the quantized transform coefficients are further encoded (20) with a lossless encoding method, and the additional step (302) of removing any lossless encoding is provided prior to step b).

6. A method as claimed in any one of the preceding claims, wherein for compression, a quantized transform coefficient is produced by dividing (14) each transform coefficient by a quantizing value from the quantization table, the integer portion of the result being used as the quantized transform coefficient; and wherein the step of dequantizing the quantized transform coefficients comprises multiplying (52) each quantized transform coefficient by a corresponding quantizing value from the quantization table.

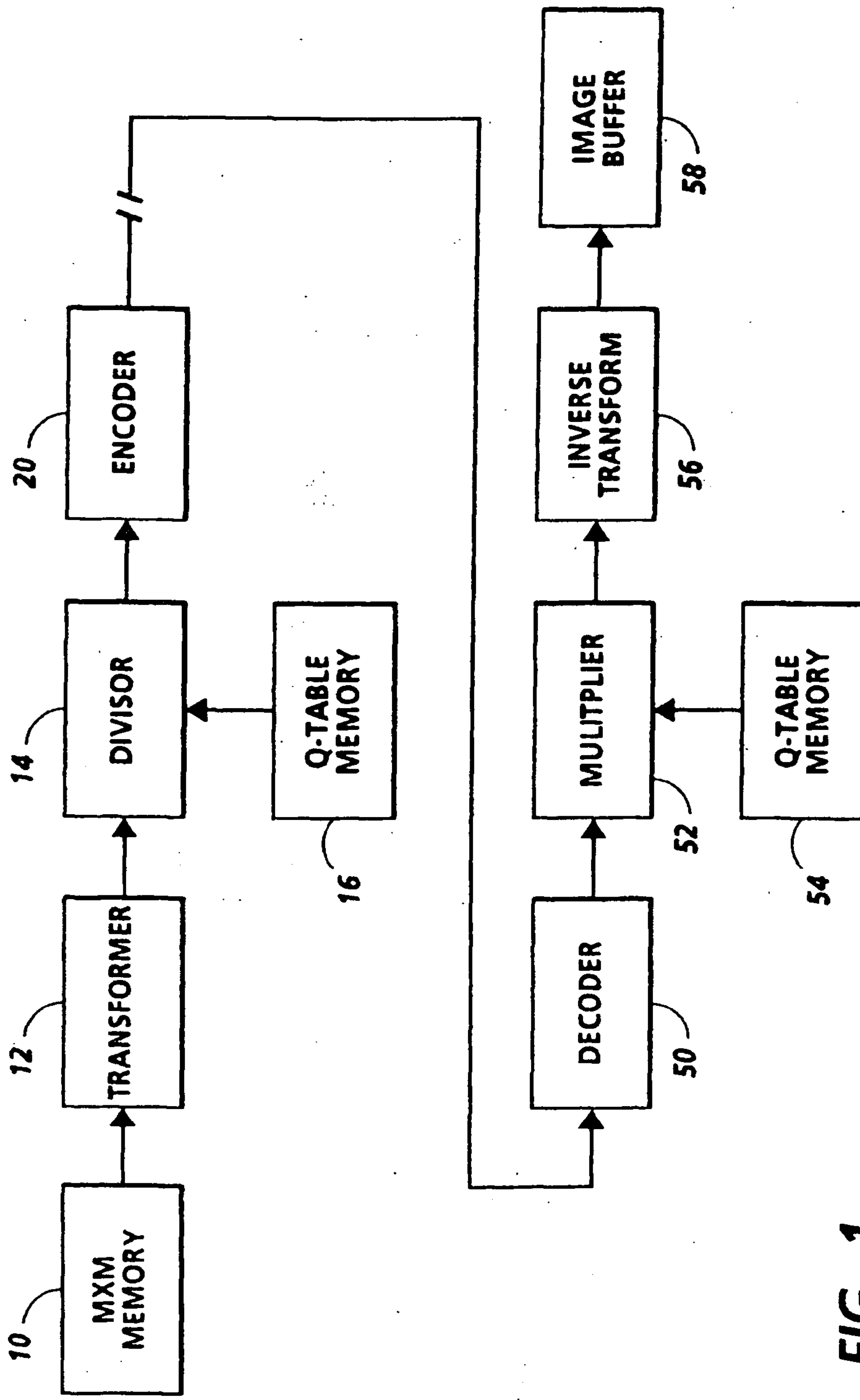

MXM MEMORY
10
TRANSFORMER
12
DIVISOR
14
Q-TABLE MEMORY
16
ENCODER
20
DECODER
50
MULITPLIER
52
Q-TABLE MEMORY
54
INVERSE TRANSFORM
56
IMAGE BUFFER
58

FIG. 1

FIG. 2A

IMAGE DATA

216	218	215	93	39	145	96	173
218	217	216	122	42	61	61	163
218	218	217	201	90	41	37	41
218	218	218	218	214	170	68	53
218	217	213	146	137	196	99	169
218	218	212	78	39	130	86	172
218	218	217	143	47	42	41	49
218	218	218	214	151	74	43	52

FIG. 2B

DCT VALUES

157	430	83	-109	-34	-28	94	-41
10	-40	56	-18	-13	-6	22	-11
-73	34	63	-58	-5	21	-8	3
14	-116	160	-1	-75	-35	78	-16
108	-53	-86	72	10	-28	9	-4
-27	50	-52	25	-14	22	-19	4
-3	-3	9	0	-8	4	2	-5
-22	20	3	-14	-2	19	-8	-8

FIG. 2C

Q-TABLE

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

FIG. 2D

QUANTIZED DCT VALUES USING Q-TABLE

10	39	8	-7	-1	-1	2	-1
1	-3	4	-1	-1	0	0	0
-5	3	4	-2	0	0	0	0
1	-7	7	0	-1	0	1	0
6	-2	-2	1	0	0	0	0
-1	1	-1	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

FIG. 3A

DCT COEFFICIENTS (MULTIPLY FIG. 2C VALUES BY FIG. 2D)

160	429	80	-112	-24	-40	102	-62
12	-36	56	-19	-26	0	0	0
-70	40	64	-48	0	-1	0	0
14	-119	154	0	-51	0	80	-1
108	-44	-74	56	0	0	0	0
-24	35	-55	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0

FIG. 3B

DECOMPRESSED IMAGE

220	214	220	102	45	137	97	180
220	231	204	119	37	64	62	145
204	237	212	192	111	61	25	55
205	224	225	228	187	156	64	58
229	207	213	155	133	197	121	165
224	199	206	96	40	123	74	168
211	211	213	141	60	66	11	82
221	234	214	212	143	85	25	53

FIG. 4

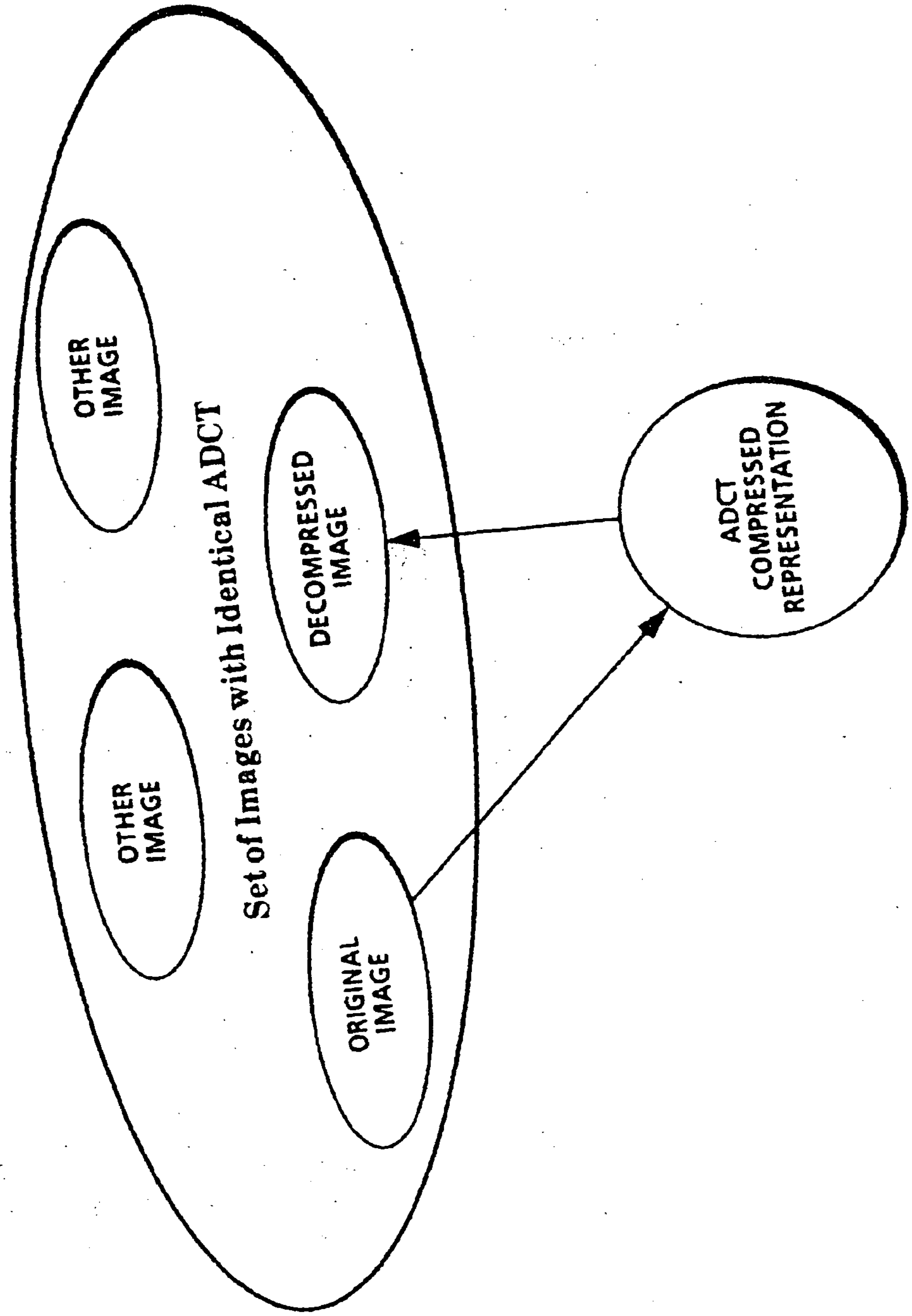

Set of Images with Identical ADCT
OTHER IMAGE
OTHER IMAGE
DECOMPRESSED IMAGE
ORIGINAL IMAGE
ADCT COMPRESSED REPRESENTATION

FIG. 5A

Possible Source Images

100

216	218	215	93	39	145	96	173
218	217	216	122	42	61	61	163
218	218	217	201	90	41	37	41
218	218	218	218	214	170	68	53
218	217	213	146	137	196	99	169
218	218	212	78	39	130	86	172
218	218	217	143	47	42	41	49
218	218	218	214	151	74	43	52

108

DCT

102

220	214	220	102	45	137	97	180
220	231	204	119	37	64	62	145
204	237	212	192	111	61	25	55
205	224	225	228	187	156	64	58
229	207	213	155	133	197	121	165
224	199	206	96	40	123	74	168
211	211	213	141	60	66	11	82
221	234	214	212	143	85	25	53

DCT

104

215	217	219	115	50	136	97	193
217	218	216	111	50	51	53	143
215	218	216	208	110	52	55	54
216	217	216	209	190	168	55	65
218	216	214	142	142	177	124	165
217	213	211	95	62	129	66	165
218	214	211	141	64	58	35	66
222	218	215	214	143	69	42	45

DCT

106

217	216	218	115	50	136	97	189
218	218	212	110	51	53	60	145
214	224	219	199	115	57	41	52
213	217	220	218	183	158	58	65
216	214	214	143	141	192	122	166
216	212	208	96	55	125	74	166
217	214	212	142	62	65	18	75
220	219	218	213	142	74	33	46

DCT

TO:
FIG. 5B

FIG. 5B

DCT Coefficients

110

157	430	83	-109	-34	-28	94	-41
10	-40	56	-18	-13	-6	22	-11
-73	34	63	-58	-5	21	-8	3
14	-116	160	-1	-75	-35	78	-16
108	-53	-86	72	10	-28	9	-4
-27	50	-52	25	-14	22	-19	4
-3	-3	9	0	-8	4	2	-5
-22	20	3	-14	-2	19	-8	-8

118

Quantization

112

160	429	80	-112	-24	-40	102	-62
12	-36	56	-19	-26	0	0	0
-70	40	64	-48	0	-1	0	0
14	-119	154	0	-51	0	80	-1
108	-44	-74	56	0	0	0	0
-24	35	-55	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0

Quantization

114

163	424	75	-112	-17	-33	89	-34
15	-42	56	-28	-13	-4	16	-6
-68	39	56	-57	3	18	-5	-1
21	-111	144	-7	-57	-37	73	-10
99	-50	-63	53	3	-11	4	-8
-12	31	-45	17	-2	10	0	-16
14	-6	-6	-5	4	9	-3	-10
4	-3	5	-11	-4	26	-24	6

Quantization

116

162	424	75	-113	-19	-38	97	-42
16	-41	57	-23	-15	-1	7	1
-69	40	56	-53	6	13	-2	0
21	-118	147	-4	-57	-26	69	-12
100	-49	-68	51	1	-3	3	-9
-16	39	-46	8	3	8	2	-17
10	-1	-6	-3	0	7	-5	-5
5	-1	0	-1	-5	9	-8	1

Quantization

FROM:
FIG. 5A

TO:
FIG. 5C

FIG. 5C

Quantized DCT Coefficients 120

10	39	8	-7	-1	-1	2	-1
1	-3	4	-1	-1	0	0	0
-5	3	4	-2	0	0	0	0
1	-7	7	0	-1	0	1	0
6	-2	-2	1	0	0	0	0
-1	1	-1	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Q-Table 119

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

FROM:
FIG. 5B

FIG. 6

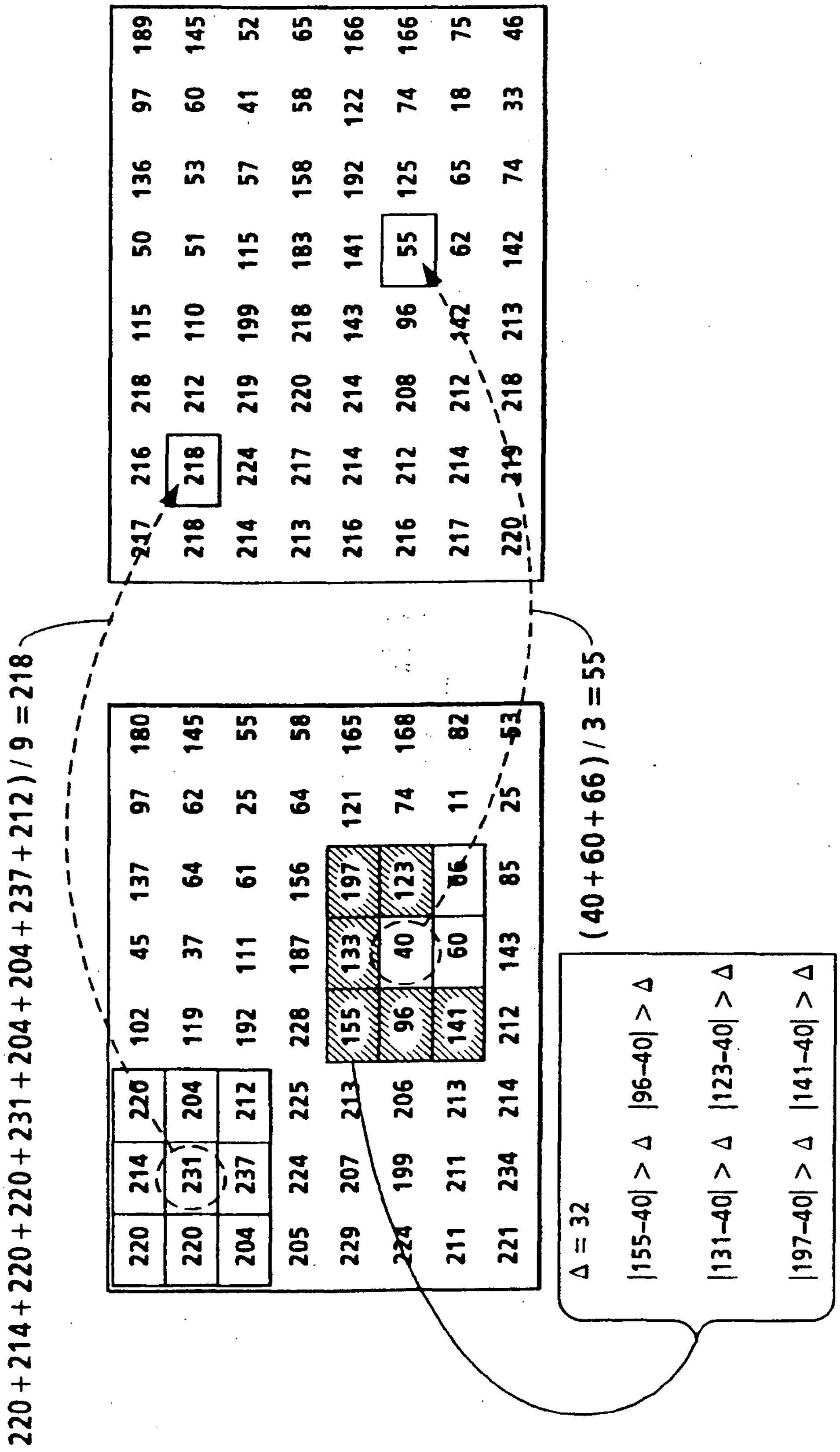

(220 + 214 + 220 + 220 + 231 + 204 + 204 + 237 + 212) / 9 = 218
(40 + 60 + 66) / 3 = 55
Δ = 32
|155−40| > Δ
|96−40| > Δ
|131−40| > Δ
|123−40| > Δ
|197−40| > Δ
|141−40| > Δ

FIG. 7A

201	201	231	209	124	57	51	62	58	15
220	220	214	220	102	45	137	97	180	110
220	220	231	204	119	37	64	62	145	197
204	204	237	212	192	111	61	25	55	93
205	205	224	225	228	187	156	64	58	20
229	229	207	213	155	133	197	121	165	79
224	224	199	$\boxed{206}$	96	40	123	74	168	63
211	211	211	213	141	60	66	11	82	43
221	221	234	214	212	143	85	25	53	101
221	221	234	214	212	143	85	25	53	101

FIG. 7B

217	216	218	115	50	137	97	188
218	218	212	110	51	53	60	145
214	224	219	198	115	57	40	52
213	217	220	219	183	158	59	64
216	214	214	144	141	192	122	166
216	212	$\boxed{208}$	96	55	125	74	166
217	214	212	142	62	65	18	74
220	219	218	213	142	74	33	46

FIG. 7C

162	424	74	-113	-19	-38	97	-42
16	-41	57	-23	-15	-1	7	1
-69	40	56	-53	6	13	-2	0
22	-118	147	-4	-57	-26	69	-12
100	-49	-68	51	1	-3	3	-9
-16	39	-46	8	3	8	2	-17
10	-1	-6	-3	0	7	-5	-5
5	-1	0	-1	-5	9	-8	1

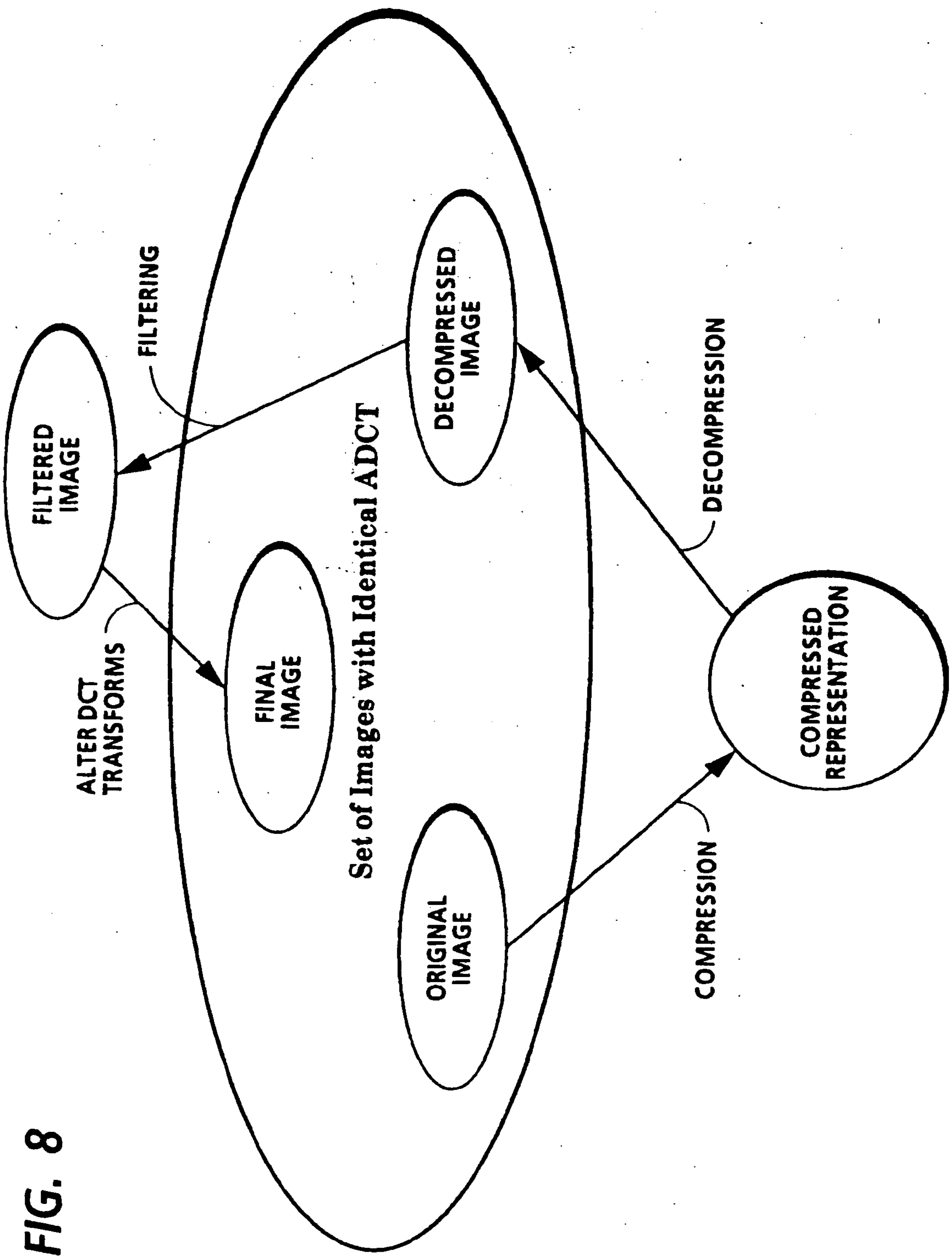
FIG. 7D

162	424	75	-113	-19	-38	97	-42
16	-41	57	-23	-15	-1	7	1
-69	40	56	-53	6	13	-2	0
21	-118	147	-4	-57	-26	69	-12
100	-49	-68	51	1	-3	3	-9
-16	39	-46	8	3	8	2	-17
10	-1	-6	-3	0	7	-5	-5
5	-1	0	-1	-5	9	-8	1

FIG. 7E

217	216	218	115	50	136	97	189
218	218	212	110	51	53	60	145
214	224	219	199	115	57	41	52
213	217	220	218	183	158	58	65
216	214	214	143	141	192	122	166
216	212	208	96	55	125	74	166
217	214	212	142	62	65	18	75
220	219	218	213	142	74	33	46

FIG. 8


FILTERED IMAGE
FILTERING
DECOMPRESSED IMAGE
DECOMPRESSION
Set of Images with Identical ADCT
FINAL IMAGE
ALTER DCT TRANSFORMS
ORIGINAL IMAGE
COMPRESSION
COMPRESSED REPRESENTATION

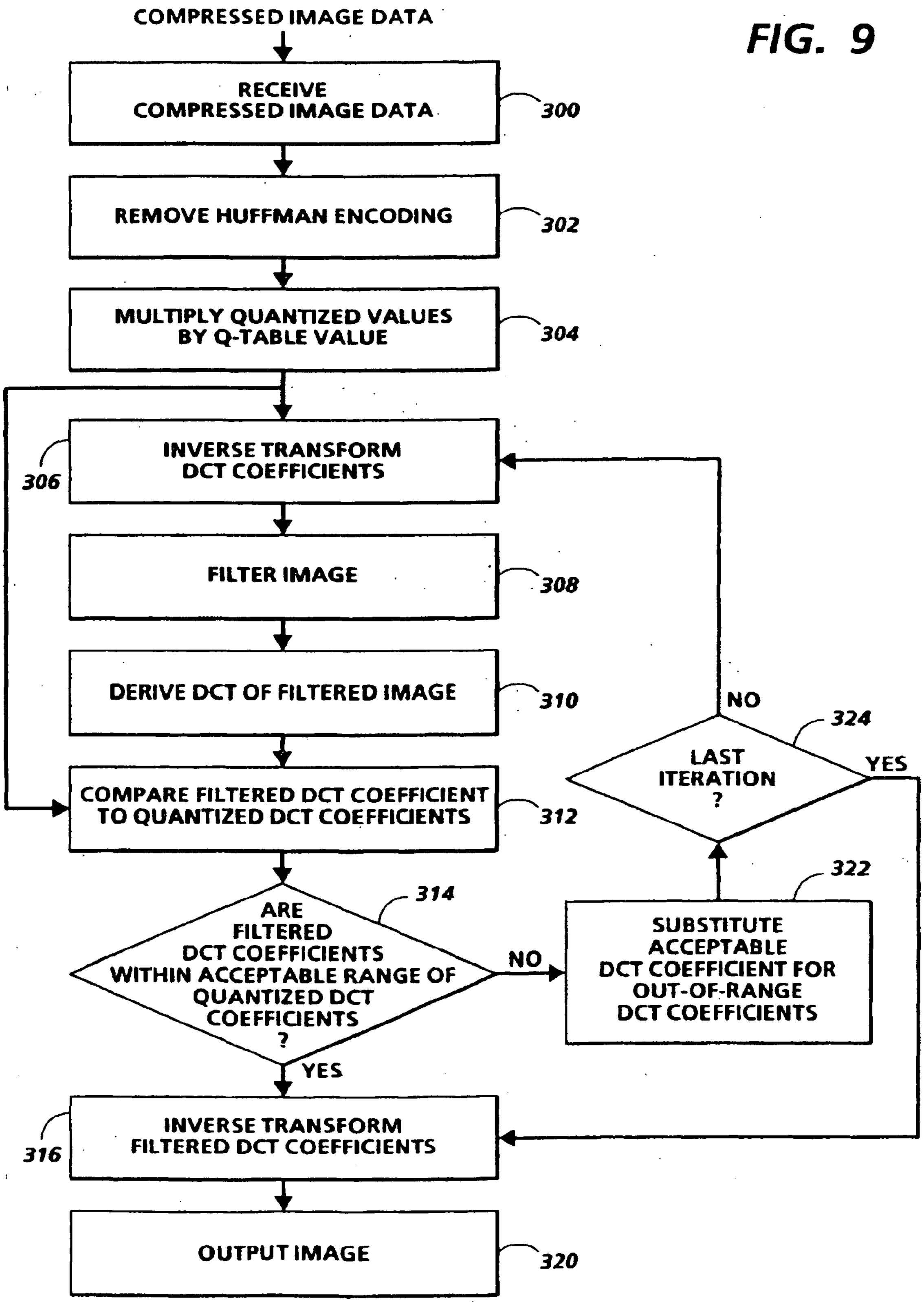

COMPRESSED IMAGE DATA
RECEIVE COMPRESSED IMAGE DATA
300
REMOVE HUFFMAN ENCODING
302
MULTIPLY QUANTIZED VALUES BY Q-TABLE VALUE
304
INVERSE TRANSFORM DCT COEFFICIENTS
306
FILTER IMAGE
308
DERIVE DCT OF FILTERED IMAGE
310
COMPARE FILTERED DCT COEFFICIENT TO QUANTIZED DCT COEFFICIENTS
312
ARE FILTERED DCT COEFFICIENTS WITHIN ACCEPTABLE RANGE OF QUANTIZED DCT COEFFICIENTS ?
314
NO
YES
SUBSTITUTE ACCEPTABLE DCT COEFFICIENT FOR OUT-OF-RANGE DCT COEFFICIENTS
322
LAST ITERATION ?
324
NO
YES
INVERSE TRANSFORM FILTERED DCT COEFFICIENTS
316
OUTPUT IMAGE
320

FIG. 9

This Page Blank (uspto)